Examining Pair Dynamics in Shared, Co-located Augmented Reality Narratives

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ABSTRACT

Augmented reality (AR) allows users to experience stories together in the same physical space. However, little is known about the experience of sharing AR narratives with others. Much of our current understanding is derived from multi-user VR applications, which can differ significantly in presence, social interaction, and spatial awareness from narratives and other entertainment content designed for AR head-worn displays. To understand the dynamics of multi-user, co-located, AR storytelling, we conducted an exploratory study involving three original AR narratives. Participants experienced each narrative alone or in pairs via the Microsoft Hololens 2. We collected qualitative and quantitative data from 42 participants through questionnaires and post-experience semi-structured interviews. Results indicate participants enjoyed experiencing AR narratives together and revealed five themes relevant to the design of multi-user, co-located AR narratives. We discuss the implications of these themes and provide design recommendations for AR experience designers and storytellers regarding the impact of interaction, physical space, spatial coherence, and narrative timing. Our findings highlight the importance of exploring both user interactions and pair interactions as factors in AR storytelling research.

CCS CONCEPTS

• **Human-centered computing** → **Mixed / augmented reality**; **Collaborative and social computing**.

KEYWORDS

augmented reality, co-location, storytelling, exhibition

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1 INTRODUCTION

Virtual reality (VR) and augmented reality (AR) are emerging and powerful mediums for storytelling. They can elicit deep and rich emotional responses, including heightened feelings of presence and engagement [19, 32]. In addition to inspiring action and fostering empathy with emotionally compelling narratives [20], AR experiences can also be anchored to a physical location and experienced by multiple people simultaneously. In this work, we developed three experiences that explore different interaction and narrative techniques and studied the perceptions and behavior of pairs in a shared, co-located setting.

Much of what we know about shared, co-located immersive narratives is based on VR multiplayer experiences, such as remote learning setups, or task-based experiments [11]. While these provide useful insights, they certainly differ qualitatively from stories and other entertainment applications experienced in groups using AR HWDs (head-worn displays). In particular, there is still much to be uncovered regarding how the presence of other individuals influences one's experience of an AR narrative.

In co-located AR narratives, players can see each other in plain sight and communicate readily about what they see—in contrast to many VR narratives that require users to navigate a virtual environment independently or to communicate via avatar representations that limit expressiveness. Communication is the basis for cooperation and collaboration, promoting teamwork, problem-solving, and collective achievements, all of which can promote comprehension and enhance the experience of shared narratives. Furthermore, shared experiences can also facilitate social engagement and promote socialization. By incorporating these features into AR narratives, creators can build experiences that encourage

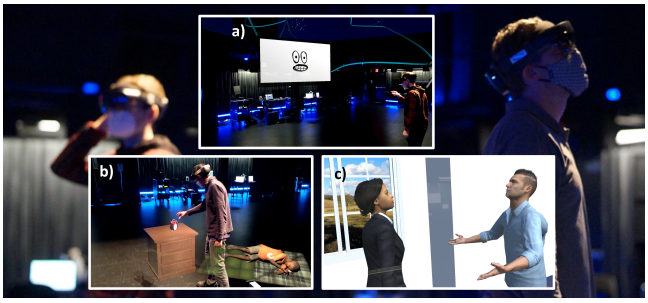

Figure 1: Screenshots of the three narratives mentioned in this paper as seen by one of the participants. a) *Phenomenal Things*, b) *Sentiments*, c) *Spill*. Background: Two users share an experience together.

social interaction and create immersive, engaging, and socially rich experiences.

To better understand shared AR narratives, we conducted an exploratory study involving three interactive AR narratives. Our goal was not to compare the narratives directly but to investigate how pairs coordinate the shared experience. We also explored how pairs negotiate the physical space with each other and other virtual elements in the narratives. Participants experienced the narratives in pairs, as this was the simplest condition that enabled us to observe inter-person interactions [31] without the logistical challenges of working with a group of players. We also include some participants who experienced the narratives by themselves, for contrast. Our study focused on two main research questions: **(RQ1)** *How do pairs understand and engage in shared spatial AR narrative interactions?* and **(RQ2)** *How do pairs relate and share the space with human partners and characters in spatial AR narratives?*

Through analysis of questionnaire responses and interview data, we identify five themes concerning how paired users experience shared AR stories. Our contributions are as follows: (1) an account of the interaction dynamics of pairs within shared AR narrative environments, including narrative communication patterns and understanding, collaborative behaviors, and mutual influence on narrative engagement, (2) an analysis of how shared space affects the way pairs move around in augmented reality environment with virtual characters and obstacles, and (3) a set of design considerations to assist AR storytellers in conceptualizing and developing AR narratives for multiple users.

2 RELATED WORK

The simplest type of immersive narrative is the 360-degree video. Elmezeny et al. [5] conducted a qualitative analysis, observing feelings of immersion, of eighteen 360-degree videos featuring clear narratives and covering different genres. The genres included action, documentary, and drama. The authors found that these immersive experiences are structured similarly to 2D experiences, relying on traditional storytelling suspense techniques (mystery, disparity of knowledge, emotional connection, as well as auditory elements). In addition to traditional storytelling suspense techniques, AR can leverage interactivity and the player's physical space as part of the storytelling experience. These narratives offer a blend of virtual and real-world elements, enhancing the sense of presence and agency for participants.

2.1 Interactivity

The interactivity of AR narratives allows users to actively engage with digital objects, manipulate their surroundings, and affect narratives, but determining the right amount of interactivity can be challenging. Zhang et al. [33] compared three versions of the experience in regard to interactivity: low interactivity, where the system controls the entire experience; medium interactivity, where the system helps the player with travel and information access, but leaves interaction to the players; and high interactivity, where all three aspects are player-controlled. The authors found that players felt significantly less engaged and challenged in the low interactivity condition; however, no significant difference was found in learning gains.

2.2 Spatial Engagement

One of the key distinguishing features of AR narratives is the opportunity for spatial engagement, by overlaying digital content onto the real world. Asobo Studio's Fragments [1], an AR crime mystery game, demonstrates this by allowing players to interact with virtual characters, and virtual objects whose placements are based on the physical world. Shin et al. [21] conducted a study which used Fragments to compare space-adaptation in two differently sized rooms (large and small) and furniture (fully or sparsely furnished). They found that although large spaces can facilitate a higher sense of presence, fully furnished rooms raised the perceived workload. With this in mind, we conducted our study in a large empty environment to accommodate for different virtual spatial layouts.

2.3 Co-located, Shared AR Experiences

In VR, the users cannot see each other except by using avatars. This requires effective avatarization, in order for the users to feel their actions are adequately represented [7]. AR, however, allows users to see each other in their real physical forms when co-located. While there are multiple types of co-located, shared AR experiences [28], all require balancing coordinate system registration and design across participants.

Dagan et al. [4] created five smartphone-based multi-player AR applications. The most relevant of these is *Feeture Film*, an interactive narrative game designed to be played by parents and children. This game, like our narratives, involves a pair (a parent and a child) interacting within the same narratives. In another study of sharing, Franz et al. [6] evaluated three techniques for sharing the experience of a museum exhibit when only one person is wearing an AR HWD. The most effective approach was to provide spatially registered anchor points, promoting common ground, coupled with explanatory figures and text on a wall display, providing context. In contrast, displaying a real-time view of the AR camera burdened the HWD wearer.

Miller et al. [15] conducted a more in-depth study of paired AR interaction. They describe three studies that examined how the presence of AR characters affect tasks in the physical world, how social interactions in AR affect subsequent nonverbal behavior in

the real world, and how occlusion affects face-to-face interaction in AR. Together, they found evidence that AR characters can influence performance by social pressure and induce participants to follow social norms. They also found that participants wearing an HWD tend to have lower social presence compared to non-users. In our case, all participants wore an AR HWD.

Even as our understanding of synchronization improves, there is few research explicitly on how synchronization affects AR storytelling in shared environments. Swearingen & Swearingen [25] describe a mobile AR experience that allows players to cooperate in two narratives of reconciliation. The game is designed so that more than one player is required to complete it. The goal is to get four birds to fly back onto a tree branch by manipulating its position while avoiding storm clouds. Braun [2] describes another collaborative experience which incorporates more traditional narrative aspects, such as virtual characters (ghosts) and a dramatic plot. The experience was designed for outdoors and supported multiple players. While both these studies provide insight into narrative AR for mobile applications, neither provides clarity on co-located narrative experiences.

3 AR EXPERIENCE DEVELOPMENT

Three shared, co-located AR narratives were developed: *Phenomenal Things*, *Sentiments*, and *Spill*. They were based on original stories and written to be experienced as immersive interactive narratives. All three experiences were developed for the Microsoft HoloLens 2 headset [14], using the Unity 3D Game engine [27] and the Photon networking library [18] to synchronize interaction between players. Calibration of the coordinate system was achieved with a combination of visual markers and Azure Spatial anchors [13]. The models of the characters in *Spill* and *Sentiments* were from Microsoft Rocketbox [8]. The models for *Phenomenal Things* were custom-made. The three narratives spanned the comedy, drama, and fantasy genres. We opted to develop narratives of varying genres to capture a range of social and emotional responses. Furthermore, varying the genre can reduce the monotony of the study tasks. Table 1 contains additional details of the narratives.

3.1 Overview of Stories

3.1.1 Phenomenal Things. This narrative provides a comical look into the daily lives of Internet of Things (IoT) devices and their experiences as social beings. The experience places the player in the IoT devices' digital realm, where the characters welcome a new lightbulb to their network. Although there is a moment of sadness when the old lightbulb passes away, the tone of the story is light-hearted and funny, and is best characterized as comedy.

3.1.2 Sentiments. This narrative explores the complex relationships between a parent and their child. In the story, the player relives the memories of a mother and her son as recent immigrants with little resources. The story is told from the mother's perspective, in a chronological sequence that depicts significant events in their lives. The story ends with an uplifting tone as the son discovers that he was able to help his mother. Due to the story's emotionally-driven plot and portrayal of real-life scenarios, this work can be categorized as a drama.

3.1.3 Spill. This narrative generally has a mysterious tone. It places the players in the middle of an unassuming party, where they must try to uncover the host's secrets. The players walk around to eavesdrop on the surrounding characters' conversations in order to hear keywords required for entry to the host's secret chamber. If a player successfully enters the secret chamber, they find a magical circle that serves as a portal to another world. Additionally, the players can interact with the virtual objects through the environment to elicit actions from the characters. This work contains situations that transcend natural laws and logic and can, therefore, be categorized as a fantasy. Unlike *Phenomenal Things* and *Sentiments*, *Spill* includes virtual walls to assist the players in eavesdropping on the other characters.

3.2 Spatial and Sound Design

3.2.1 Phenomenal Things. The characters in *Phenomenal Things* (Fig. 2-a) and IoT elements are positioned around the edges of the space, leaving the center empty for players to walk. Since the characters were located at the borders of the space the audio was spatialized to ensure that the character speaking could be easily located.

3.2.2 Sentiments. In *Sentiments*, the virtual rooms are only partially rendered and most of the player view is dominated by the physical environment. For most of the story, only one character is visible – the son (Fig. 2-b). In some scenes, the son is absent, and the player only hears his disembodied voice from a 3D location outside the visual scene. To highlight the immaterial nature of memories, the story uses a "fade out" effect to transition between the scenes.

3.2.3 Spill. The setting for *Spill* is the interior of a house, which includes realistic characters (Fig. 2-c) windows, doors, walls, and furniture. This causes most of the physical environment to be occluded by virtual imagery. In the story, the players are guests at a party. During the party, they are tasked with eavesdropping on the virtual partygoers' conversations. Since the story uses spatial audio, the players must get close to a character's position in order to hear what is being said.

3.3 Interaction Dimension: Interaction Techniques, Narrative Effect, Complexity

The narratives include different forms of interaction—for example, moving close to a character to trigger a story event, using hand gestures to interact with objects, or using voice commands to progress the story. Some interactions are required to progress, while others are available to engender a sense of immersion and encourage exploration. Fig. 3 illustrates typical interactions in the stories.

3.3.1 Phenomenal Things. This narrative uses proxemics (i.e., the players' position relative to other characters[12]) as the main mode of interaction. The players can "befriend" characters by moving closer to them (Fig. 3-a). "Befriending" a character changes its social network and introduces a bias that modifies the version of the story being told. The biases included: (1) the corporate bias, where the young bulb wants to be the best possible bulb, (2) the artistic bias, where it wants to make the most of its days and not worry about death, and (3) the conspiratorial bias, where it wanted to find a way to live forever. Regardless of the bias, all versions of the story

Table 1: Contrasting design factors of each AR story based on Narrative, Presentation, and Interaction Dimensions.

		Phenomenal Things	Sentiments	Spill
Narrative	**Genre**	Comedy	Drama	Fantasy
	Setting	Cyberspace	Collection of Memories	House Party
Presentation	**Visual Style**	Cartoon	Photorealistic	Photorealistic
	Characters	Anthropomorphic Objects	Virtual Humans	Virtual Humans
	Dialogue	Heavy	Light	Heavy
Interaction	**Techniques**	Proximity	Hand Gestures	Hand Gestures and Voice Control
	Effect	Plot Change	Scene Advance	Story Advance
	Complexity	Low Complexity	High Complexity	Medium Complexity

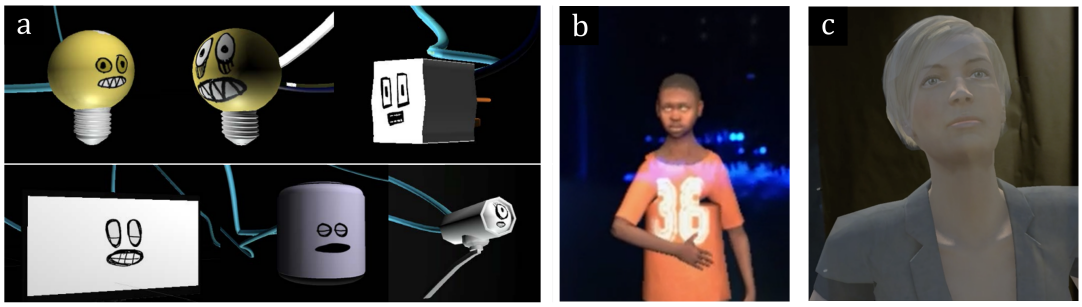

Figure 2: Depictions of characters in each narrative: (a) The sentient IoT devices of *Phenomenal Things*, (b) the "Kid" of *Sentiments*, (c) Non-player party attendee in *Spill*.

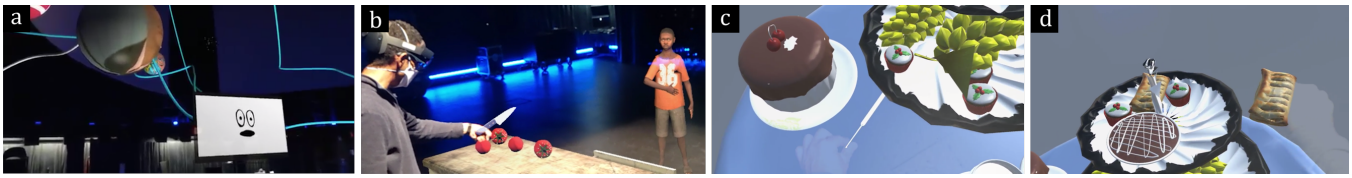

Figure 3: Interaction methods available within each narrative: (a) A player "friends" a character in *Phenomenal Things* by being spatially close to them, (b) In *Sentiments*, a player grabs a knife to cut tomatoes, (c) A player uses a pinching gesture to grab a white lock pick in *Spill*, (d) A player uses *Spill*'s grabs a piece of virtual dessert.

eventually converge towards the same ending. Therefore, "befriending" is optional. However, "befriending" changes specific events throughout the plot. The complexity of the proxemic interaction can be regarded as low, as it did not require any additional interaction outside of the player moving towards the virtual character, which they did naturally. Even if the player did not move towards any of the characters, the narrative would automatically progress towards a pre-determined ending.

3.3.2 Sentiments. This narrative presents more explicit opportunities for interaction with objects in each scene. For example, players can turn off the alarm when the son says it is early or chop tomatoes when he asks for dinner (Fig. 3-b). Interactable objects are highlighted in blue when the player looks at them and can be grabbed by the player by closing their hand while near them. Some scenes require sequential interactions, such as picking up the car keys and then opening the door. Once the actions are completed, the story advances to the next scene. Alternatively, the story automatically progresses, towards its pre-determined ending, if players do not complete the required interaction after a set time. This ensures that all players see the entire experience. *Sentiments*' interactions are considerably more complex than *Phenomenal Things* as it requires players to not only use items to complete specific actions, but also complete them in a specific order.

3.3.3 Spill. Players can pick up many of the virtual items in *Spill* using hand gestures. The players do not need to interact with all items; most interactive items are only there to give a sense of being at a party (e.g., plates of food). The players can either use pinching (Fig. 3-c) or grabbing (Fig. 3-d) motions to select the items. The only mandatory gestural interaction sequence involves picking up a lock pick and using it to open a closed door. A voice-based command or "code" must also be used to complete the story. The players learn the code by carefully eavesdropping on the characters. If the characters discover the players eavesdropping on them, the player receives a warning, which can influence the storytelling. Receiving three warnings requires the player to restart the story. To complete the story, the code must be spoken at a specific location in the house. *Spill* requires fewer interactions to complete than *Sentiments*, since only two interactions are mandatory.

3.4 Collaboration Dimension

Here we discuss the extent to which each narrative was shared. Each narrative was designed to achieve varying degrees of co-presence, the sense of being together in a shared space [29]. Both *Phenomenal Things* and *Sentiments* were synchronized by location, each contained location markers so paired players could maintain a sense of how and where their partner was moving through the space. Furthermore, in *Sentiments*, players were able to see the actions of one another. If the first player interacted with an object, for example, a knife to cut tomatoes, the second player could see the knife in the first player's hand. Spill was spatially and temporally synchronized, so players had the sense of being at the party together and could eavesdrop on guests individually or together. However, key story progression events were not shared between players. For example, each player needed to use the lock pick individually to transition into the alternate dimension.

4 METHODS

The goal of our exploratory study is to shed light on how pairs experience spatial AR narratives, to identify areas for future research and to inform design. The research questions are: **(RQ1)** How do pairs understand, communicate, and engage in shared spatial AR narrative interactions?, and **(RQ2)** How do pairs relate and share the space with human partners and other characters in spatial AR narratives? Our focus is not on determining how specific narrative elements (e.g., art style, plot, theme, genre) impact the player experience. Rather, we vary the narratives in order to explore a range of narrative styles and to keep our participants engaged throughout the study. The study was approved by Virginia Tech's Institutional Review Board (protocol #21-788).

4.1 Apparatus and Study Setting

We conducted a within-subjects study with the three narratives as the single factor. The study was set in a large performance and theater space at our institution. The ample space (40 ft. by 32 ft.) allowed the participants to freely watch, listen, and interact with the characters and virtual objects. The theater had a remote workstation, which allowed us to control the experience from a distance. The participants used a Microsoft HoloLens 2, an optical see-through AR headset. The study took 45 minutes to complete.

4.2 Participants

We recruited 25 pairs of participants at Virginia Tech via the institution's electronic mailing list. Participants could register for the study in pairs or ask to be paired with another participant. Due in part to issues related to COVID-19, 17 pairs (34 participants) participated, while another 8 participated independently without their intended partner. These individual participants are analyzed separately, giving us some insight into how sharing the experiences differs from engaging alone. The participants had varying levels of familiarity with AR, ranging from somewhat novice to expert. Six participants rated their expertise with AR as average or above. Eight of the pairs knew each other.

4.3 Measures

To capture the experience, we used two questionnaires and a semi-structured interview. For each story, we asked participants to complete an adapted version of the **Immersive Experience Questionnaire** (IEQ), where the references to *game* were changed to *story*. The IEQ score aggregates components measuring emotional involvement, cognitive involvement, real-world dissociation, and challenge control [9]. The IEQ was selected as it measures dimensions for immersion and presence, which are critical for understanding how paired users engage with and perceive the AR narrative environment. This questionnaire also provides insight into how the pairs connected cognitively and emotionally to the narrative.

We asked participants to fill a **Shared Narrative Questionnaire**. It was used to rate their agreement to statements on narrative, understanding the interactions, and shared experience on a 5-point Likert scale. Narrative: "I found the characters engaging", "The narrative was easy to understand", "I felt I was in the presence of other characters". Interaction: "I understood I was freely able to interact", "I understood how the interaction worked". Shared experience: "I found myself communicating with my partner", "I found the shared experience inconsistent", "I found it easy to share my experience with someone else". This custom questionnaire was included to help capture how pairs feel connected to their partners and the characters throughout the narrative. This questionnaire also provides insight into how the pairs feel their interaction influenced the narratives.

We concluded the study with a **semi-structured interview**. We interviewed pairs together and recorded comments through note-taking. The participants were asked four questions: (1) Can you describe, in very basic terms, what each story was about?, (2) Were you constantly aware of being in the company of another participant?, (3) Did you feel the need to communicate with the other participant in the study? If so, how?, and (4) Did you find it distracting to have another participant in the study?

4.4 Procedure

Upon arrival, investigators described the study to the participants and verbally obtained their consent. Then, we asked the pair if they knew each other. After headset fitting and calibration, participants completed the three narratives. The order of the stories was not controlled, but the majority of the participants experienced them in order of interaction complexity: (1) *Phenomenal Things*, (2) *Sentiments*, and (3) *Spill*. After each narrative, participants completed the Immersive Experience Questionnaire and the Shared Narrative Questionnaire, followed by the semi-structured interview.

5 RESULTS AND ANALYSIS

5.1 Quantitative Analysis

All statistical analyses were conducted using R version 4.3.2 [26]. Wilcoxon tests used the implementation for the package *rstatix*, version 0.7.2 [10]. We set $\alpha = 0.05$ for statistical significance. To avoid paradoxical results [16], we did not perform an omnibus test and directly tested the comparisons of interest. We report raw z-scores and p-values adjusted for family-wise error with Holm. We also report the median and median absolute deviation (MAD).

5.1.1 Adapted Immersive Experience Questionnaire. Scores from the adapted Immersive Experience Questionnaire (Fig. 4) for *Phenomenal Things* ranged between 63 and 127 (Median=99, MAD=22.2), *Sentiments* between 67 and 128 (Median=108, MAD=11.9),and for *Spill* between 76 and 135 (Median=112, MAD=24.5). Wilcoxon signed-rank tests indicated no significant difference between *Phenomenal Things* and *Sentiments* (z=-.966, p=.668), *Spill* and *Sentiments* (z=-.523, p=.668). or *Phenomenal Things* and *Spill* (z=-2.29, p=.067).

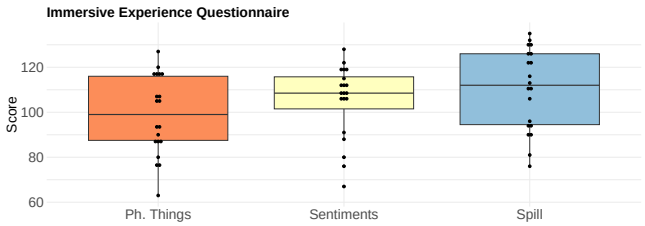

Figure 4: Scores of the adapted Immersive Experience Questionnaire

5.1.2 Shared Narrative Questionnaire. We divided the analysis of our Shared Narrative Questionnaire into the perceptions about characters and narratives, sharing the experience with another person, and interaction. For each group, we performed a Wilcoxon signed-rank test with Holm adjustment. On questions related to story perception, we found no significant difference between *Phenomenal Things* and *Sentiments* (z=.0514, p=.959) or *Spill* and *Sentiments* (z=2.16, p=.061). We found a significant difference between *Phenomenal Things* and *Spill* (z=.24, p=.049). Participants felt less need to communicate with the characters in *Phenomenal Things* and had more issues understanding the story of *Spill* (Fig. 5).

Regarding the questions about sharing the experience with a participant, we found a significant difference between *Phenomenal Things* and *Sentiments* (z=-3.61, p=<.001) using Wilcoxon signed-rank tests with Holm adjustment. The tests also showed a significant difference between *Phenomenal Things* and *Spill* (z=-2.76, p=.012). We did not find a significant difference between *Sentiments* and *Spill* (z=1.35, p=.177). Most participants found the experience to be easy and that the shared experience was consistent. A large majority felt that the story was more enjoyable because it was experienced with someone else (Fig. 6).

Two questions were included to gauge understanding of the interaction techniques and perception of interaction agency within the experience. Wilcoxon signed-rank tests with Holm adjustment. We found that significantly more participants in *Phenomenal Things* reported not understanding the interaction when compared to *Spill* (z=-2.98, p=.009). There was no significant difference in this regard between *Sentiments* and *Phenomenal Things* (z=-2.13, p=.067) or *Sentiments* and *Spill* (z=-1.31, p=.191). Additional information is available in Fig. 6).

5.2 Thematic Analysis

We analyzed our interview data for common themes, following the bottom-up approach described in Braun & Clarke [3]. This approach

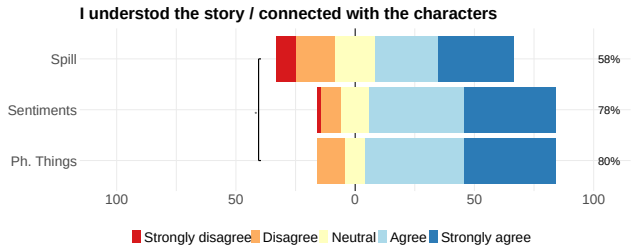

Figure 5: Narrative-related questions. Participants understood the story and connected with the character. Brackets indicate statistical significance after adjustment for multiple comparisons.

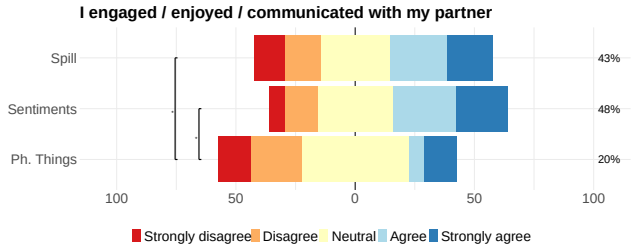

Figure 6: Shared Experience-related questions. Participants were significantly less engaged as a pair in *Phenomenal Things*. Brackets indicate statistical significance after adjustment for multiple comparisons.

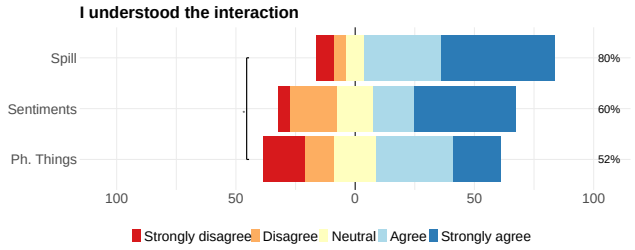

Figure 7: Interaction-related questions. Most participants did not understand or notice *Phenomenal Things* interaction. Brackets indicate statistical significance after adjustment for multiple comparisons.

is suitable for exploratory research, as it helps researchers identify emergent themes [24, 30]. The notes collected during the interview were annotated for clarity and identification of critical thoughts by Author 1. Author 1 performed an initial review of the notes in order to reduce the raw data into more generalizable themes. Author 3 repeated this approach and both compared their findings to determine the most appropriate codes to be extracted from the data. These newly generated codes were then reviewed by the remaining team members, after which the data was re-coded accordingly. Common topics included the story, spatial audio, physical space, technical details, communication, and interaction. The team then grouped the codes to identify the most salient themes uncovered from the data and possible relationships between the codes.

5.2.1 Theme 1: Interacting as a pair. This theme concerns how participants perceived the opportunities for interaction and used them as a way to share the experience (n = 8). We found that the interactions supported the participant's desire to collaborate. However, we also found that awareness and timing of the interaction were critical. We did not find information on how the paired experience affected the pairs' experiences with the characters.

Awareness of interactions (P01, P05): The interaction was better and smoother when there were some indicators of interactivity. Participants reported being unsure of what items were interactive in each of the experiences. P05, in particular, had difficulty in knowing how to interact with certain objects: "wasn't 100% sure what objects were interactable, [...] we had to turn off [the] TV but weren't able to turn it off. We were wondering what we were supposed to do." Users also did not know what to do with the objects after they had picked up an object, as referenced by P01: "didn't know exactly what to do just like the car keys one I picked up keys and couldn't figure out how to open the door."

Relying on other participants for task completion (P08, P09, P16, P39): According to P08, they would communicate with their partner to accomplish tasks or get help. P16 indicated that they "communicated when [they] needed confirmation" with their partner to ensure correct task completion. P39, due to their lack of familiarity with the HoloLens, communicated with their partner for help with the technology: "It was helpful to communicate in the second (*Sentiments*) and third story (*Spill*). I'm not used to VR, it was cool to have someone with me." P09 was excited to have someone to share their reactions with, P09: "I could reflect any reactions to the person if I felt like it."

Timings and structure of interactions (P11, P32, P38): The timing and length of the interactions impacted participant experience. P11 felt the interactions ended too quickly, stating, "[in *Sentiments*,] after cutting tomato [I] wanted to do more." Several participants expressed disappointment in not being able to redo any interactions that they may have missed; P32: "couldn't tell what was prompting [transitions]– kind of had to be there at the right time or you would miss it."

5.2.2 Theme 2: Challenges and benefits of AR spatialization. Spatial sound and visuals affected participant orientation and interaction (n = 4). The spatialization of the narrative prompted participants to move and orient themselves according to visuals and sounds. We identified two codes under this theme:

Reorienting to new scenes (P02, P21): Scene changes required participants to take time to reorient themselves. This was especially severe in *Sentiments* as the vignettes did not provide full 360-degree coverage and would appear at different locations within the theater space, as expressed by P02: "[in the] second story the settings would kind of [be] in its own space but was disorienting to find the scene".

Spatial audio localization (P01): The spatial audio in both *Phenomenal Things* and *Spill* was found to be effective in assisting participants to quickly locate the characters speaking and orient themselves within the scene. This is noted by P01 who stated: "[the] audio was dynamic, so I knew which way to turn [my] head in [*Phenomenal Things*] and [*Spill*]". P38 noticed a mismatch between the audio and visuals: "[in *Spill*] the audio did not feel like it matched with the visuals" (this was echoed by a solo participant. See subsection 5.2.6).

Physical movement within the space (P38): The narrative structure added to how immersed the user felt in the physical space. It also influenced how the user preferred to move around the space. P38 summarized this well: "It depends on the story. For the first one [*Phenomenal Things*] I really did not want to walk. I felt like an audience so I did not interact with it. For the second one [*Sentiments*], I felt that I needed to walk. There are different scenes. [...] I felt more engaged and that I felt like walking."

5.2.3 Theme 3: AR benefits to the narrative. This theme concerns how interaction, spatialization, and movement improved the participant's experience (n = 8). We found that participants enjoyed moving around in the space and considered the experience comfortable and immersive. We identified the following codes:

Comfort and Enjoyment (P02, P05): Some users provided additional context to their experience by comparing the AR technologies to other storytelling methods. Participants found the AR experiences to be overall more comfortable than VR ones, and more dynamic than traditional 2D cinematic experiences. P02, in particular, appreciated that they had "a lot more control over the experience" and had options to "go up [to] and look and inspect" the virtual characters. P05 enjoyed that the AR experiences provide a large viewing space, stating that "compar[ing] this to VR I feel like [AR] is more comfortable. Compared to [a] smartphone [whose screen] is too small, so [I was] more satisfied [with AR]". P02 enjoyed navigating around the scene instead of only being able to view it from one location. P02 stated that AR experiences have a "cool dynamic that theaters don't get where they watch what they want you to see. You can watch the backs [of the characters]."

AR integration (P05, P38, P39): Participants felt that visuals helped them feel *in* the story. P38 reported that the walls, in *Spill*, helped them feel more engaged in the story: "walking around and being physically engaged with the space made it feel more physical, more multi-sensory even though it was in virtual space." Two participants also reported that they enjoyed the balance between the virtual and the physical world. P05 stated that they "could check my watch in [*Phenomenal Things*] and be in [two different] realities"

Goal oriented interactivity (P04, P32, P36): Having task-related interactions assisted participants with their ability to understand the narrative, especially in *Sentiments*; P36 stated: "interacting and having a task helped with following the story [in *Sentiments*]." In fact, participant P04 reported that they would have enjoyed simply being an observer within the narrative. P04 enjoyed the fact that *Phenomenal Things* had more art than the other narratives: "More art, less 'playability' would be nice. The first one [*Phenomenal Things*] was excellent." They felt the experience was more like an art exhibition and did not feel as though they wanted to be a direct part of the experience.

5.2.4 Theme 4: Narrative's visual-temporal influence on player experience. This theme concerns how timing and visual realism impacted participants' ability and desire to collaborate (n=10). The

narrative visual structure was noted as a motivation to communicate and explore the space. On the other hand, visual issues and low visual fidelity were seen as distracting.

Desire for collaboration may depend on the story (P04, P22): As reflected by P22, collaboration may vary based on the narrative. P22 stated: "The first (*Phenomenal Things*) didn't matter [if the participant was there]. The second (*Sentiments*) and third (*Spill*) [did]". Due to the less realistic nature of *Phenomenal Things*, P04 was less able to communicate with their partner, as indicated: "I [communicated with my partner more] in [*Sentiments*] but maybe because *Phenomenal Things* was surreal."

Timing of scene transitions (P01, P11, P26): The timing of the scene transitions was shown to create difficulties for the participants' sense of presence, interactivity and engagement, particularly in *Sentiments*. P01 found it difficult to remain aware of their partner when the scenes were changing, stating: "[at] times it detracted, especially during transitions with another person coming into the scene." P11 and P26 felt that *Sentiments* moved too quickly for them to fully enjoy the interactions that were available; P11 stated: "the scenes shifted so fast."

Presentation Issues (P01, P05, P11, P22, P24, P39): Visual problems were disconcerting for the participants. P01, P05, P11, and P22 experienced inconsistent frame rates. P01 reported losing balance due to the lag: "during [*Sentiments*], it lagged when transition[ing] but my perspective didn't shift and I thought I was going to fall." P24 expressed difficulties distinguishing between the intended experience and the technical errors: "It was difficult to distinguish when something was happening as part of the program and when something was glitching." Additionally, the character models' lips erroneously stopped moving during speeches, which made it difficult for P39 to determine which characters were speaking. P39 stated: "Sometimes it was hard to tell, ... sometimes the mouth was not moving." Meanwhile, P5 noticed the broken hand animation: "... attention to detail on the model [was] not the best...kid's hand was broken unintentionally."

5.2.5 Theme 5: Walking in shared AR spaces. This theme concerns how object presence and interpersonal distance influenced participant's walking patterns (n = 5). We found that, although roaming in an open space, participants remained aware of each other and negotiated their movement through space. The movement was also influenced by the illusion of place, as participants would avoid walking into objects and walls. Within this theme, we identified the following codes:

Influence of virtual walls (P02, P19): In addition to furniture, *Spill* also rendered virtual walls. The virtual walls in *Spill* further enhanced the experience as P19 stated: "The walls make it more encompassing." Conversely, the presence of the walls made some users nervous as they did not want to walk into them, as represented by P02: "I was in an environment and I didn't want to walk through walls".

Avoid collisions with partners (P05, P24, P38): P05, P24, and P38 indicated that they had to communicate with the other players to avoid colliding with them. P05 indicated: "In [*Spill*], I was avoiding hitting [my partner]. We were talking to one another in [*Sentiments*] and [*Spill*] to avoid collisions." P38 went further in expressing how the lack of markers in Sentiment made them more hesitant in traversing the AR scene, stating: "I was worried if I was going to bump on the second one [*Sentiments*] because there was not a marker on the person. The internet of things [*Phenomenal Things*] had a marker on the other participant; that is helpful."

5.2.6 Codes and Themes of Solo Participants. We analyzed the eight solo participants and did not identify any new theme. We found two new codes supporting the Spatial Audio/Visuals and Narrative:

Audio propagation issues (P21) — Spatial Audio/Visuals Theme: This participant found the audio in *Spill* to be effective. However, since the spatial audio was not attenuated by the virtual walls, there were areas in the experience where the sound was louder than expected. This is referenced by P21: "I wondered if the character was in closer proximity to me through the wall; it was closer than the characters right in front of me." Additionally, P21 had difficulty recognizing that the scene may have been behind them P21: "it is also hard because I didn't realize there was something behind me." P31 said that the story was "immersive [because] it felt like it was part of the world." P37 stated that "having interaction definitely made it seem more in-depth; being able to change things in a scene definitely made it closer in – somewhat video-game-like, since it's you making the choices."

Characters and story structure (P21, P26)—Narrative Theme: These participants gravitated toward characters that were playful and had bold personalities. They also liked the characters that tried to endear themselves to the participants as P21 states: "*Phenomenal Things* may be easier to relate [to], because they were cartoons. Got attached to the sad old lightbulb." As mentioned in Section 3.1.1, the old lightbulb passes away and is recycled. On the other hand, some participants did not connect well with more realistic characters, or characters that had broken animation. P21 implied the effect of the Uncanny Valley when they described their dislike of the human characters: "I kind of wondered if the humans made it harder for me to engage, because it wasn't [really] a human." The solo participants enjoyed narratives that were well-structured like *Phenomenal Things* and *Sentiments*. However, they disliked the open-ended narrative structure of Spill, because they had difficulties understanding the context of the story. P26 summarized this point well: "the third story [Spill] had very little context."

6 DISCUSSION

In this section, we discuss the results in the context of the two research questions.

6.1 *RQ1: How do pairs understand and engage in shared spatial AR narrative interactions?*

Being in a pair created opportunities for verbal communication, perspective-sharing, collaborative sense-making of specific narrative events and spatial orientation, which assisted paired participants' overall understanding and engagement with the narrative that did not exist for individual participants. Three themes surfaced related to how pairs explored interactions and how different narrative aspects affected their ability and interest in collaborating

(Theme 1, Theme 2, and Theme 4). Combined, they point to how certain spatial and design aspects supported interaction and, in turn, pair interaction gave rise to task coordination (Fig. 8).

Before interaction was possible, participants had to orient themselves in the space to identify important characters and elements they could interact with. Orientation was challenging in *Sentiments* which consisted of multiple scenes with different spatial layouts, compared to the fixed layout of *Spill* and *Phenomenal Things*. Having a pair provided a level of comfort for some participants who were less familiar with AR. This finding is also reflected in the results of the Shared Experience Questionnaire (Fig. 6), which indicates that participants felt more need to communicate in *Sentiments* and *Spill* than *Phenomenal Things*. It should also be noted that some participants had varying preferences on the amount of interactivity they desired. In certain cases, participants wanted to observe the characters and not necessarily engage with them.

Another challenge in *Sentiments* and *Spill* was to make sense of certain narrative events and then perform the appropriate interactions. Some scenes in *Sentiments* required multiple steps (e.g., picking up the keys prior to opening the door), while *Spill* had conversations happening simultaneously throughout the space. These more complex interactions led participants to help each other, resulting in more communication between the pairs than would happen otherwise. This was further illustrated by some of the individual participants who preferred structured narratives like *Phenomenal Things* and *Sentiments* over the open-ended narrative of *Spill*. Players found that having a partner helped them to confirm

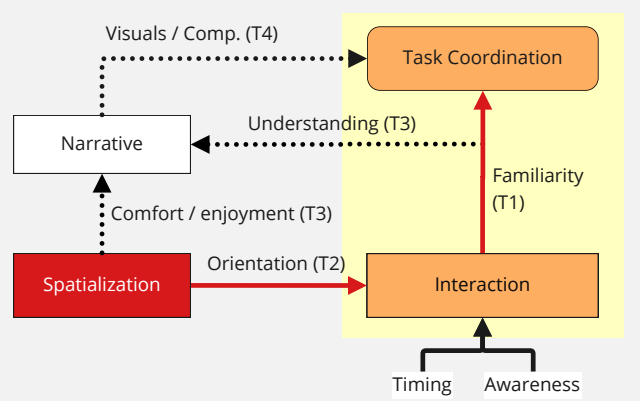

Figure 8: Relationship between AR spatialization (red), narrative (white), and pair interaction (yellow). Red arrows indicate the path from spatialization to task coordination. Dotted arrows indicate narrative-mediated impacts. Audiovisual spatialization oriented participants towards interactions (Theme 2) while familiarity with interaction prompted task coordination (Theme 1). Spatialization also led to an increase in comfort and enjoyment of the narrative (Theme 3) while visual realism drove the desire to collaborate (Theme 4). Pair interaction also improved the understanding of the narrative (Theme 3).

their thoughts and ideas regarding the story. Additionally, participants also communicated to confirm they were completing the interactions correctly.

The interaction type and integration with the story also impacted how the pairs approach to collaborative interaction. The significance of being a pair was reduced in *Phenomenal Things* as one participant did not notice their partner and several others did not find having a partner necessary. *Phenomenal Things*' use of proximity-based befriending mechanics was recognized by very few participants as a way to interact with the characters. One participant described how they felt more like an audience member in *Phenomenal Things*, but felt like they needed to walk around the scenes in *Sentiments*. We attribute this perception to the subtlety of *Phenomenal Things*' interactions, as well as the materialization of scenes in *Sentiments* at different locations throughout the study space.

Finally, the audio-visual aspects of the narrative also affected participants' willingness and ability to collaborate. Most participants regarded *Phenomenal Things* as a fixed story that would progress regardless of their interactions. As such, most participants appeared to experience less need to interact with the characters and other players, likely due to *Phenomenal Things*' structure plot and more extensive dialogues.

6.2 *RQ2: How do pairs relate and share the space with human partners and characters in spatial AR narratives?*

Having the participants paired led to specific spatial awareness requirements and social factors that shaped how the participants shared the AR narrative in the presence of their partners and the virtual characters. The thematic analysis revealed three themes related to the way participants perceived their partners and characters in the story (Theme 2, Theme 4, and Theme 5). The story's spatial presentation motivated participants to move around in the space; however, moving was subject to the virtual space, characters' presence, partner's movement, and the temporal aspects of the narrative (Fig. 9).

Theme 5 indicates how participant's movement in the scene was influenced by the constraints created by the virtual objects, characters, and other people. Particularly, in *Spill*, which had several virtual walls in an otherwise completely empty physical environment, participants felt enough presence to avoid walking through the walls. The only physical obstacle was their partner. Participants generally remained aware of their partner's position throughout the three stories and kept proper social distance, even when trying to interact with the same object. A few participants specifically commented on how concerned they were about bumping into each other, which is unusual for an optical-see-through device. We speculate that the lack of human-AR occlusion reduced the participant's visibility. *Spill* had players wear "augmented hats" that served as an AR participant marker. This feature was indicated by participants as helpful in establishing the partner's location.

Additionally, participants recognized virtual characters and tried to avoid moving too close to them, corroborating Nowak & Biocca [17]'s findings that participants viewing anthropomorphic characters report more feelings of social presence than when they view

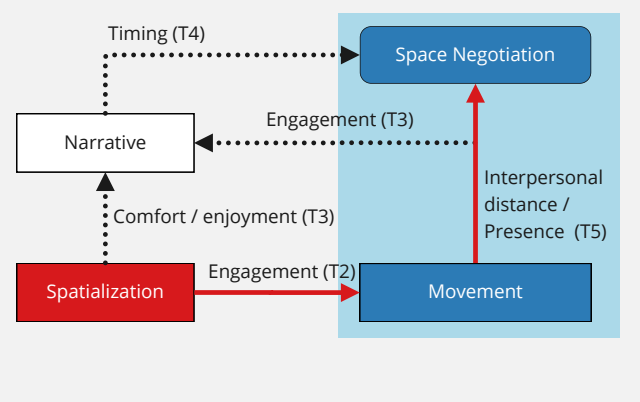

Figure 9: Relationship between AR spatialization (red), walking in shared spaces (blue), and narrative (white). Red arrows indicate the path from spatialization to space negotiation. Dotted arrows indicate narrative-mediated impacts. Engagement created by audiovisual spatialization led to physical movement in the space (Theme 2). Interpersonal distance and spatial layout considerations then led to the need to negotiate the space (Theme 5). The timing of the scene transitions in the narrative also led to space negotiation (Theme 4). The narrative benefited from increased engagement created by movement and from higher enjoyment created by the spatialization (Theme 3).

characters with low anthropomorphism. Similarly, studies by Shine et al. [21, 22] have reported that participants treat virtual humans similarly to how they would treat real physical entities. Regardless, one participant implied an Uncanny Valley effect while describing their dislike of the human characters. Conversely, another participant felt it was easier to relate to the cartoon non-anthropomorphic characters of *Phenomenal Things*. These conflicting ideas could be a result of participants' varying levels of suspension of disbelief due to the virtual character's personalities and stories. Strongly established narrative worlds and characters with well-developed backstories may have lead to some participants relating to the characters on a deeper level overlooking their visual appearance and more readily embracing the fictional reality [23].

Narrative spatialization made participants feel present in the story world, making them more engaged with the events and characters, prompting them to walk in the scene. In *Spill* and *Sentiments*, walking was used to explore the space, observe the scene from different angles, and reach interaction points. Participants felt less motivated to walk in *Phenomenal Things*, as the characters were organized on the edges of a large circle. While participants could walk around each of the characters, we observed participants would typically find a spot and watch the characters as the story unfolded.

6.3 Design Considerations for Shared, Co-located AR Story Development

We make the following recommendations for shared AR narratives based on the results:

Interaction Complexity. In our study, interactivity was an important mechanism in the shared experience (Theme 1). In both *Sentiments* and *Spill* participants coordinated the execution of tasks, shared their reactions, and assisted each other. While interactions should be easy to understand, they should also be intricate enough to engage both players.

Space Usage. Even though our stories ran in a large empty space we saw complex movement patterns arise as participants tried to avoid each other, the characters, and other virtual objects in the world (Theme 5). Consider adequate personal/social space around other players and story characters. In addition, correct occlusion and sound attenuation can improve players' confidence, in particular if the environment contains other physical obstacles.

Spatial Coherence. The ability to quickly understand the layout of the virtual scene relative to the physical space was important for interaction and movement (Theme 2). Changes in the layout also affected participants' ability to track their partner's positions. Stories with fixed layouts, such as *Spill* and *Phenomenal Things*, should be less distracting and easier to understand for participants.

Narrative Timing. Timing impacted how much time participants had to orient themselves in space, complete the interactions, and communicate with their partners (Theme 4). This was particularly true in *Sentiments*. Designers should consider the overhead of communication and coordination and insert enough time between transitions and dialogs for players to engage with each other.

7 LIMITATIONS

The order of the AR narratives was not counterbalanced, which meant the participants could complete later narratives with more familiarity with the AR technology. Furthermore, the pairs were interviewed together, which meant each person could influence their partner's responses. Despite this, our study can serve as a preliminary framework of how to conduct paired mixed reality studies using art exhibitions. It also outlines the potential challenges of maintaining experimental control. Enforcing experimental control is important for data collection. However, too much control can constrain player freedom and degrade their experience.

8 CONCLUSION

Our study sought to better understand the dynamics between paired participants during co-located AR storytelling. Although exploratory in nature, we uncovered several key areas for design focus when creating AR narrative entertainment. Future work should further explore how narrative affordance and prior experience with AR can impact the desire for interactivity.

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REFERENCES

[1] Asobo Studio. 2017. Fragments. https://www.asobostudio.com/games/fragments

[2] Norbert Braun. 2003. Storytelling in collaborative augmented reality environments. (2003).

[3] Virginia Braun and Victoria Clarke. 2006. Using thematic analysis in psychology. *Qualitative Research in Psychology* 3, 2 (2006), 77–101. https://doi.org/10.1191/1478088706qp063oa arXiv:https://www.tandfonline.com/doi/pdf/10.1191/1478088706qp063oa

[4] Ella Dagan, Ana María Cárdenas Gasca, Ava Robinson, Anwar Noriega, Yu Jiang Tham, Rajan Vaish, and Andrés Monroy-Hernández. 2022. Project IRL: Playful Co-Located Interactions with Mobile Augmented Reality. *Proc. ACM Hum.-Comput. Interact.* 6, CSCW1, Article 62 (apr 2022), 27 pages. https://doi.org/10.1145/3512909

[5] Ahmed Elmezeny, Nina Edenhofer, and Jeffrey Wimmer. 2018. Immersive storytelling in 360-degree videos: An analysis of interplay between narrative and technical immersion. *Journal For Virtual Worlds Research* 11, 1 (2018).

[6] Juliano Franz, Mohammed Alnusayri, Joseph Malloch, and Derek Reilly. 2019. A comparative evaluation of techniques for sharing AR experiences in museums. *Proceedings of the ACM on Human-Computer Interaction* 3, CSCW (2019), 1–20.

[7] Adélaïde Genay, Anatole Lécuyer, and Martin Hachet. 2022. Being an Avatar "for Real": A Survey on Virtual Embodiment in Augmented Reality. *IEEE Transactions on Visualization and Computer Graphics* 28, 12 (2022), 5071–5090. https://doi.org/10.1109/TVCG.2021.3099290

[8] Mar Gonzalez-Franco, Eyal Ofek, Ye Pan, Angus Antley, Anthony Steed, Bernhard Spanlang, Antonella Maselli, Domna Banakou, Nuria Pelechano, Sergio Orts-Escolano, et al. 2020. The rocketbox library and the utility of freely available rigged avatars. *Frontiers in virtual reality* 1 (2020), 561558.

[9] Charlene Jennett, Anna L Cox, Paul Cairns, Samira Dhoparee, Andrew Epps, Tim Tijs, and Alison Walton. 2008. Measuring and defining the experience of immersion in games. *International journal of human-computer studies* 66, 9 (2008), 641–661.

[10] Alboukadel Kassambara. 2023. *Pipe-Friendly Framework for Basic Statistical Tests.* R Foundation for Statistical Computing, Vienna, Austria. https://CRAN.R-project.org/package=rstatix

[11] Yue Li, Eugene Ch'ng, Sue Cobb, and Simon See. 2022. Presence and communication in hybrid virtual and augmented reality environments. *Presence: Teleoperators and Virtual Environments* 28 (2022), 29–52.

[12] Daniel Medeiros, Rafael dos Anjos, Nadia Pantidi, Kun Huang, Maurício Sousa, Craig Anslow, and Joaquim Jorge. 2021. Promoting Reality Awareness in Virtual Reality through Proxemics. In *2021 IEEE Virtual Reality and 3D User Interfaces (VR)*. 21–30. https://doi.org/10.1109/VR50410.2021.00022

[13] Microsoft. 2022. *Azure Spatial Anchors.* https://azure.microsoft.com/en-ca/products/spatial-anchors

[14] Microsoft. 2024. HoloLens 2. https://www.microsoft.com/en-ca/hololens/hardware#document-experiences

[15] Mark Roman Miller, Hanseul Jun, Fernanda Herrera, Jacob Yu Villa, Greg Welch, and Jeremy N Bailenson. 2019. Social interaction in augmented reality. *PloS one* 14, 5 (2019), e0216290.

[16] Kimihiro Noguchi, Riley S Abel, Fernando Marmolejo-Ramos, and Frank Konietschke. 2020. Nonparametric multiple comparisons. *Behavior Research Methods* 52 (2020), 489–502.

[17] Kristine L Nowak and Frank Biocca. 2003. The effect of the agency and anthropomorphism on users' sense of telepresence, copresence, and social presence in virtual environments. *Presence: Teleoperators & Virtual Environments* 12, 5 (2003), 481–494.

[18] Photon. 2023. *Photon Fusion: Setting the Benchmark for Multiplayer games.* https://www.photonengine.com/fusion

[19] Nicola S Schutte and Emma J Stilinović. 2017. Facilitating empathy through virtual reality. *Motivation and emotion* 41 (2017), 708–712.

[20] Dong-Hee Shin. 2017. The role of affordance in the experience of virtual reality learning: Technological and affective affordances in virtual reality. *Telematics and Informatics* 34, 8 (2017), 1826–1836.

[21] Jae-eun Shin, Hayun Kim, Callum Parker, Hyung-il Kim, Seoyoung Oh, and Woontack Woo. 2019. Is any room really ok? The effect of room size and furniture on presence, narrative engagement, and usability during a space-adaptive augmented reality game. In *2019 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*. IEEE, 135–144.

[22] Jae-eun Shin, Boram Yoon, Dooyoung Kim, and Woontack Woo. 2021. A user-oriented approach to space-adaptive augmentation: The effects of spatial affordance on narrative experience in an augmented reality detective game. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. 1–13.

[23] Robin JS Sloan. 2012. Why bridge the Uncanny Valley? Photorealism vs suspension of disbelief in animation. *Media Education Journal* 52 (2012), 19–22.

[24] Anselm Strauss and Juliet Corbin. 1998. Basics of qualitative research techniques. (1998).

[25] Kyoung Swearingen and Scott Swearingen. 2021. The Woods: A Mixed-Reality Multiplayer Cooperative Game. In *HCI in Games: Serious and Immersive Games: Third International Conference, HCI-Games 2021, Held as Part of the 23rd HCI International Conference, HCII 2021, Virtual Event, July 24–29, 2021, Proceedings, Part II.* Springer, 388–397.

[26] R Core Team. 2021. *R: A Language and Environment for Statistical Computing.* R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/

[27] Unity. 2024. Unity Real-Time Development Platform | 3D, 2D, VR & AR Engine. https://unity.com/

[28] Robby van Delden, Steven Gerritsen, Dirk Heylen, and Dennis Reidsma. 2018. Co-located augmented play-spaces: past, present, and perspectives. *Journal on Multimodal User Interfaces* 12, 3 (01 Sep 2018), 225–255. https://doi.org/10.1007/s12193-018-0269-z

[29] Xiangyu Wang and Rui Wang. 2011. Co-Presence in mixed reality-mediated collaborative design space. *Collaborative Design in Virtual Environments* (2011), 51–64.

[30] David Wicks. 2017. The coding manual for qualitative researchers. *Qualitative research in organizations and management: an international journal* 12, 2 (2017), 169–170.

[31] Kipling D Williams. 2010. Dyads can be groups (and often are). *Small Group Research* 41, 2 (2010), 268–274.

[32] Shuran Yang and Wenxiang Zhang. 2022. Presence and flow in the context of Virtual Reality storytelling: what influences enjoyment in virtual environments? *Cyberpsychology, Behavior, and Social Networking* 25, 2 (2022), 101–109.

[33] Lei Zhang, Doug A Bowman, and Caroline N Jones. 2019. Exploring Effects of Interactivity on Learning with Interactive Storytelling in Immersive Virtual Reality. In *2019 11th International Conference on Virtual Worlds and Games for Serious Applications (VS-Games)*. IEEE, 1–8.